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14. ABSTRACT

One of the most significant air traffic challenges is managing the National Airspace System (NAS) in a manner that optimizes efficiency and mitigates avoidable delay, while maintaining safety, when convective weather is present. To do this, aviation planners seek to develop strategic air traffic management (ATM) plans and initiatives that anticipate weather constraints 2-8 hours in the future and identify options and alternatives for efficient operations during the off-nominal NAS conditions. In support of strategic planning, traffic managers currently conduct bi-hourly Strategic Planning Telcons (SPTs) and devise weather impact mitigations plans using the human-generated Collaborative Convective Forecast Product (CCFP). However, most operational decision-makers agree that the quasi-deterministic CCFP "polygons" (accompanied by a "low/high" forecast confidence rating) lack the granularity and temporal resolution to adequately support efficient strategic ATM plans and decisions. Moreover, traffic managers also assert that probabilistic forecasts of convective weather likelihood, while helpful in highlighting regions of possible airspace disruptions, generally lack the ability to resolve specific weather characteristics pertinent to strategic planning.
MIT Lincoln Laboratory, NCAR Research Applications Laboratory, and NOAA Earth Systems Research Laboratory (ESRL) have collaborated to develop a high-resolution, rapidly updating 0-8 hour deterministic precipitation and echo tops forecast, known as CoSPA, to aid operational decision-makers in developing strategic plans for weather impact mitigation. In the summer of 2010, a comprehensive field study was conducted to assess potential benefits and the operational performance of CoSPA in the context of strategic ATM planning. The data were gathered by simultaneous real-time observations of I5 FAA and airline operations facilities during 15 convective weather impact days affecting the Northern Plains, Great Lakes, and East Coast regions of the NAS.
CoSPA field evaluation results will be presented to demonstrate the various ways aviation planners have utilized the increased spatial and temporal resolution of CoSPA - the ability of CoSPA to resolve storm structure and refine forecasts with high update rates - to make more detailed assessments of potential weather impacts and to determine the subsequent need for airspace management initiatives. Results will also be presented that highlight CoSPA enhancement needs, primarily related to forecast uncertainty, that would improve the operational effectiveness of CoSPA-derived weather impact mitigation plans. Finally, opportunities to translate CoSPA deterministic forecasts into integrated weather-ATM decision support for specific strategic planning tasks will be discussed.

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US OF A HIGH-RESOLUTION DETERMINISTIC WEATHER FORECAST FOR STRATEGIC AIR TRAFIC MANAGEMENT DECISION SUPPORT*

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1. INTRODUCTION

One of the most significant air traffic challenges is managing the National Airspace System (NAS) in a manner that optimizes efficiency and mitigates avoidable delay, while maintaining safety, when convective weather is present. To do this, aviation planners seek to develop strategic air traffic management (ATM) plans and initiatives that anticipate weather constraints 2–8 hours in the future and identify options and alternatives for efficient operations during the off-nominal NAS conditions. With accurate predictions of weather constraints, aviation planners can execute efficient strategic traffic management initiatives such as Airspace Flow Programs (AFP; Brennan, 2007), Ground Delay Programs, Strategic "Playbook" reroutes, etc., in an effort to mitigate avoidable air traffic delay.

In support of strategic planning, traffic managers currently conduct bi-hourly Strategic Planning Telecoms (SPTs) and devise weather impact mitigation plans using the human-generated Collaborative Convective Forecast Product (CCFP). However, most operational decision-makers agree that the quasi-deterministic CCFP "polygons" (accompanying by a "low/high" forecast confidence rating) lack the granularity and temporal resolution to adequately support efficient strategic ATM plans and decisions.

Recent advances in strategic weather forecast technology include the CoSPA forecast. CoSPA is a high resolution (3 km) 0 – 8 hr deterministic forecast (updating every 15 minutes) of precipitation and echo tops. CoSPA uses Corridor Integrated Weather System (CIWS) short-term forecast techniques, numerical weather predictions from the High Resolution Rapid Refresh (HRRR) model for longer-term forecasts, and technologies to "blend" the two for its seamless radar-like presentation of storm evolution. A detailed description of the CoSPA forecast technology and displays is presented in Section 2 of this paper.

In 2010, a field evaluation was conducted at 17 FAA and airline dispatch facilities to assess the ATM strategic planning utility and estimated delay reduction benefits of the CoSPA weather forecast. Simultaneous, real-time observations of CoSPA usage were made on 15 convective weather days during June – September 2010. A description of the design and methodology of this experiment, including details on how cost savings were estimated for observed beneficial decisions derived from CoSPA, is presented in Section 3 of this paper.

The observed CoSPA operational benefits included more efficient strategic planning initiatives (such as AFP and Playbook reroute execution), enhanced common situational awareness of anticipated weather constraints on airspace capacity, and improved collaborative decision-making when developing strategic plans. CoSPA was also used frequently by Center Weather Service Unit (CWSU) meteorologists in FAA En Route Centers and weather specialists at the Air Traffic Control System Command Center (ATCSCC) to assist with their tasks – including CCFP collaboration and development. Results demonstrating the frequency of CoSPA use at each facility, observed delay mitigation and decision coordination benefits based on use of the forecast, and quantified delay savings (per use and as an annual estimate) are presented in Section 4 of this paper.

2. COSPA FORECAST TOOL

CoSPA is a high resolution (3 km) 0 – 8 hour forecast (updated every 15 minutes) of Vertically Integrated Liquid Water (VIL) precipitation and

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echo tops. CoSPA capabilities available for the 2010 Operational Evaluation included:

1) *Current and Past Weather:* Current weather and up to eight hours of past weather including satellite, VIL precipitation and echo tops for the Contiguous United States (CONUS). Resolution is 1 km and update rate is 2.5 min. Additional weather information included:
   a. Cloud-to-ground Lightning Data (1 min update rate)
   b. Storm Motion Vectors, Echo Top Tags, and Storm Growth and Decay Trends Contours (2.5 min update rate)
   c. Standard and Winter Precipitation settings

2) *Corridor Integrated Weather System (CIWS) Forecasts:* 0 – 2 hour (5 minute increments) deterministic forecast of VIL precipitation and echo tops for the CONUS. Additional features included:
   a. Forecast and verification contours for precipitation and echo tops
   b. 5 minute update rate at 1 km resolution
   c. Forecast Accuracy Scores for precipitation and echo tops
   d. Both Standard and Winter Precipitation settings

3) *CoSPA Forecast:* 2 – 8 hour deterministic forecasts of precipitation and echo tops for the CONUS. Forecast information included:
   a. Forecast and verification contours for precipitation and echo tops
   b. 15 minute update rate at 3 km resolution

4) CCFP Overlay: The 2, 4, and 6 hour CCFP polygons were provided as an overlay on the CoSPA forecast product.

The CIWS/CoSPA situation display (SD) was used to show the current weather situation and forecasts of precipitation and echo tops via forecast animation loops, static forecast images, and contour overlays. The SD functionality was robust, with agile panning and zooming available via mouse control. An operator could focus the SD to the terminal level with pixel resolution of 1 km (0.5 nm) and continuously zoom out to full CONUS with 7 km resolution (4 nm) pixels.

Users had the option of viewing the forecast in both tactical and strategic modes (See Figure 2-1). The tactical mode ("2hr Fcst" button) showed CIWS 0-2 hr forecasts for the full CONUS and was primarily intended for shorter term operational decisions. In the tactical mode, two hours of past weather was available in an animation loop and the forecast frame rate was adjustable from 5 minutes to 1 hour.

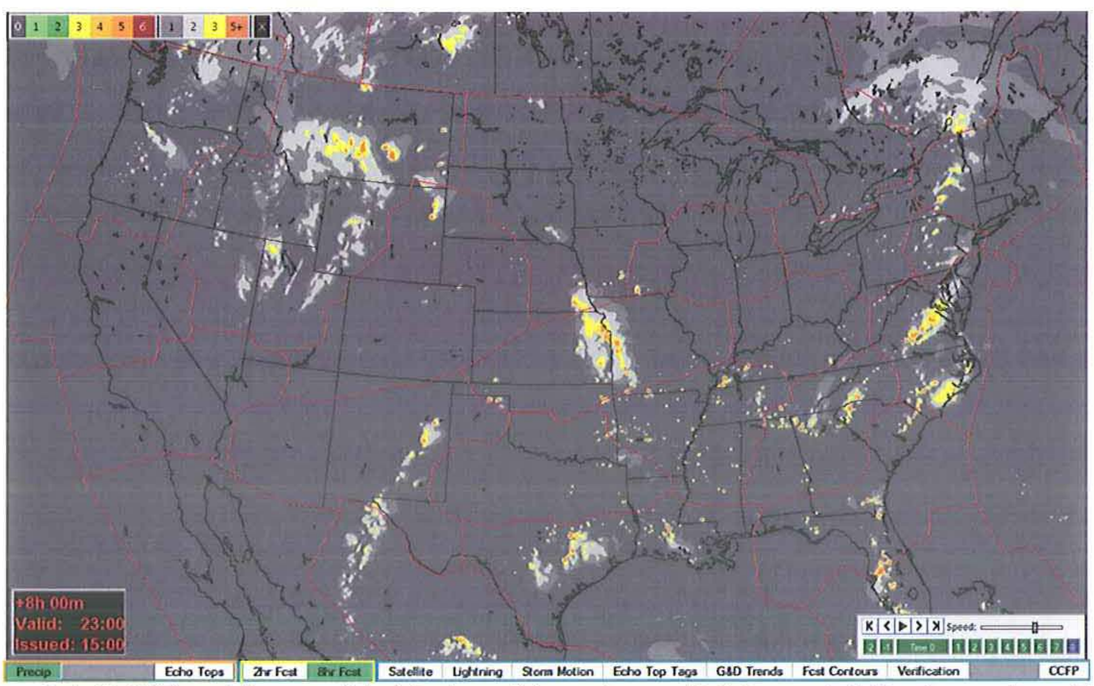

Figure 2-1. CoSPA and its associated features (shown here with 8-hr precipitation forecast enabled).

The CoSPA strategic mode ("8hr Fcst" button) is intended for longer-term planning as well as short-term situational awareness. For the strategic mode, the display could run in an animation loop mode, with up to 8 hours of past weather that transitioned into a forecast with 8 hours of future weather for the full CONUS. The user could also adjust the frame rate frequency to 15 min, 30 min, or 60 min time steps. To assess the performance of CoSPA forecasts, previous forecasts could be evaluated by activating the "Verification" contours product on the CoSPA SD. With "Verification" enabled, forecasted contours of level 3+ precipitation or 30 kft+ echo tops, valid at the current time, are overlaid on the current precipitation and echo tops images, respectively, for direct comparison.

Additional CoSPA weather features that could be enabled on past and current weather frames of the CoSPA animation include key products such as Growth and Decay Trends and Echo Tops Tags. The "G&D Trends" product shows current storm growth and decay areas that had been changing over the past 15 to 18 min. The Echo Tops Tags allows users to view the estimated storm top heights, with 1kft resolution, as an overlay on the Precip or Echo Tops gridded products.

The CoSPA forecast (Wolfson et al. 2007) is comprised of three primary components: the heuristic extrapolation forecast, the HRRR numerical model, and the blending algorithm (Dupree et al. 2009; Weygandt et al. 2010; Pinto et al. 2010). For the 0-2 hour forecast, CIWS technology is used.

<u>Extrapolation Forecast</u>**:** The CoSPA extrapolation technique was designed to adapt and improve upon the advection techniques used in CIWS. The 0-2 hour forecast uses an Eulerian-like extrapolation technique which works well for short-term motion; however, to obtain forecasts out to 8 hours, larger scales are necessary. The motion prediction consists of three fundamental steps: 1) filtering and tracking, 2) interpolation of motion fields, and 3) advection of the weather (see Dupree et al. 2009).

<u>High Resolution Rapid Refresh (HRRR):</u> An experimental version of the Weather Research and Forecasting (WRF) model called the HRRR model is being run at the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) Global Systems Division (GSD) laboratory. The HRRR model is a 3-km resolution model that is nested inside an experimental version of the 13-km Rapid Update Cycle (RUC) model. This version of RUC assimilates three dimensional radar reflectivity data with a method based on a diabatic Digital Filter Initialization (DFI) technique (Weygandt et al. 2010). The HRRR model is restarted every hour and generates fresh forecasts out to 15 hours. HRRR VIL forecasts have been made available at a special sub-hourly (15 minute) frequency for the CoSPA forecast system to best take advantage of the blending technology.[1]

<u>Blending:</u> The blending algorithm has been designed to combine extrapolation and model forecasts of VIL to produce a seamless, rapidly updating 0-8 hour forecast of weather intensity (Phillips et al. 2010). The blending process optimizes the overall skill of the forecast by taking advantage of the strengths of both the extrapolated and numerical model forecasts. The extrapolated forecast tends to be more accurate in shorter time horizons (0-4 hours) and the numerical model tends to be more accurate in the longer time horizons (3-8 hours). To provide an optimized forecast, blending is done through a calibration of model data, a phase correction to remove location errors in the model and statistically-based weighted averaging. In CoSPA, heuristic extrapolation forecasts of VIL are blended with VIL forecasts from the HRRR model.

3. COSPA FIELD EVALUATION AND BENEFITS ASSESSMENT METHODOLOGY

The CoSPA operational benefits study was modeled after the delay reduction methodology used for CIWS and the New York Route Availability Planning Tool (RAPT) in 2003 – 2009 (Robinson et al. 2004; Robinson et al. 2006; Robinson et al. 2008; Robinson et al. 2009). Knowledgeable observers, with in-depth

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[1]The HRRR model is launched with new observations as input every hour, publishing forecast frames every 15 min out to 15 hours specifically for use in CoSPA. (Internal to the model, forecast frames are available on time scales of seconds as the model equations are integrated forward in time, but these forecasts are usually never published.) Every 15 minutes, a new extrapolation forecast out to 8 hours is published and blended with the HRRR forecasts closest to the valid time of the extrapolation forecasts.

understanding of how to use and interpret CoSPA and with experience in assessing the weather-ATM decision-making environment, were present at several FAA and airline facilities during convective weather events in order to observe the operational usage and performance of both strategic weather forecasts. Observations at each facility were made simultaneously in order to better understand the coordination and collaboration interactions associated with strategic weather impact mitigation planning.

3.1 Participating Facilities and In-Field Assessment Events

In an effort to conserve resources while still assessing the forecast capabilities across a larger NAS region (with varying airspace management concerns and weather impact characteristics), observations of CoSPA use in the field were conducted using a regional approach. Field observation days were targeted as EAST or MIDWEST evaluation events, with a different group of facilities included for forecast field-use assessments depending on the regional focus. Table 3-1 lists the FAA and airline facilities included for EAST and MIDWEST evaluation events, along with the field evaluation dates for both regions in 2010. Collectively, observation teams from the FAA Aviation Weather Office, MIT Lincoln Laboratory, the National Center for Atmospheric Research (NCAR), and AvMet Applications were dispatched to 17 traffic management facilities that included the FAA Command Center (ATCSCC) and a mix of En Route Centers (ARTCCs), large terminals (TRACONs), and commercial air carriers considered primary decision-makers for strategic ATM planning.

Observations of CoSPA use in the field were conducted on 15 convective weather days (181 hours of air traffic control operations) during the 2010 summer storm season. Convective weather coverage, location, storm type, intensity, and times of storm development and decay (overall evolution) varied substantially across the 15 observations days (listed in Table 3-1), resulting in a large variety of air traffic impacts and ATM strategic planning initiatives to help mitigate delay. Therefore, these observation periods were considered a representative sample of the convective weather events that can disrupt air traffic operations in the critical Midwest and East Coast travel corridors of the NAS.

During convective weather events, observers at each participating facility routinely documented the following information:

- Weather conditions in or near the facility or airspace of interest;
- Air traffic issues or problems as a result of weather;
- Air traffic impact mitigation strategies, initiatives, or programs in place;
- Weather information being used to support air traffic strategic decision-making;
- Specific information provided by all strategic weather forecast tools (CoSPA, CCFP, etc.);
- Specific uses of strategic weather forecast products (CoSPA, CCFP, etc.);
- Impact of CoSPA, CCFP, and use of other forecasts on air traffic strategic decision-making; and
- Alternative traffic management decisions had the CoSPA decision not been made.

Observations were made several times per hour as the anticipated convective weather event evolved. Observations were most frequent during the morning hours, when strategic plans were being developed, and strategic weather forecasts were used most often to prepare for afternoon and evening traffic pushes coinciding with increased (often diurnally-driven) thunderstorm development.

The observers at the FAA and airline facilities were also available for additional, live CoSPA training. In order to build confidence in the forecast capabilities and to increase user experience, on-the-spot training was provided when questions arose. Observers took great care to note all instances when CoSPA training or additional assistance was provided. These instances were removed from the benefits-observations database in order to ensure that CoSPA benefits calculations presented in this report were based solely on unassisted usage of this forecast capability.

Table 3-1
CoSPA EAST and MIDWEST Field Evaluation Sites and Dates

<table>
<tr><th colspan="2">EAST</th><th colspan="2">MIDWEST</th></tr>
<tr><td colspan="2">ATCSCC</td><td colspan="2">ATCSCC</td></tr>
<tr><td colspan="2">Boston ARTCC (ZBW)</td><td colspan="2">Minneapolis ARTCC (ZMP)</td></tr>
<tr><td colspan="2">Washington DC ARTCC (ZDC)</td><td colspan="2">Chicago ARTCC (ZAU)</td></tr>
<tr><td colspan="2">Indianapolis ARTCC (ZID)</td><td colspan="2">Kansas City ARTCC (ZKC)</td></tr>
<tr><td colspan="2">NY ARTCC (ZNY)</td><td colspan="2">Chicago TRACON (C90)</td></tr>
<tr><td colspan="2">Cleveland ARTCC (ZOB)</td><td colspan="2">Continental Airlines AOC (COA)</td></tr>
<tr><td colspan="2">Atlanta ARTCC (ZTL)</td><td colspan="2">United Airlines AOC (UAL)</td></tr>
<tr><td colspan="2">NY TRACON (N90)</td><td colspan="2">Delta Air Lines AOC (DAL)</td></tr>
<tr><td colspan="2">Continental Airlines AOC (COA)</td><td colspan="2" rowspan="3"></td></tr>
<tr><td colspan="2">Delta Air Lines AOC (DAL)</td></tr>
<tr><td colspan="2">Jet Blue Airlines AOC (JBU)</td></tr>
<tr><td colspan="2">TOTAL: 11</td><td colspan="2">TOTAL: 8</td></tr>
<tr><td>Eval – 1</td><td>13-Jun</td><td>Eval – 1</td><td>06-Jul</td></tr>
<tr><td></td><td>14-Jun</td><td></td><td>07-Jul</td></tr>
<tr><td>Eval – 2</td><td>16-Jun</td><td></td><td>08-Jul</td></tr>
<tr><td>Eval – 3</td><td>19-Jul</td><td>Eval – 2</td><td>03-Aug</td></tr>
<tr><td></td><td>20-Jul</td><td>Eval – 3</td><td>01-Sep</td></tr>
<tr><td></td><td>21-Jul</td><td></td><td>02-Sep</td></tr>
<tr><td>Eval – 4</td><td>04-Aug</td><td colspan="2" rowspan="3">ATCSCC: Air Traffic Control System Command Center
ARTCC: Air Route Traffic Control Center
TRACON: Terminal Radar Control Facility
AOC: Airline Operations Center</td></tr>
<tr><td></td><td>05-Aug</td></tr>
<tr><td>Eval – 5</td><td>16-Sep</td></tr>
</table>

3.2 METHODOLOGY FOR ESTIMATING DELAY REDUCTION BENEFITS

Using the methodology summarized in Figure 3-3, the detailed observations collected during the EAST and MIDWEST evaluation periods were used to determine the various CoSPA operational benefits, to estimate the frequency of each observed benefits category, and to estimate delay savings per beneficial decision. The most significant component of this methodology is the case study analysis of individual situations where CoSPA was the primary weather forecast tool used to make strategic planning decisions. With these case studies, it was important to not only assess the decision made based upon prototype forecast information, but to also assess what decision and outcome may have occurred had the CoSPA-derived decision not been made. The difference in traffic management outcome and the estimated differences in delay between the "beneficial" decision and the alternative or "baseline" decision is the estimated delay reduction benefit for a specific CoSPA strategic planning application.

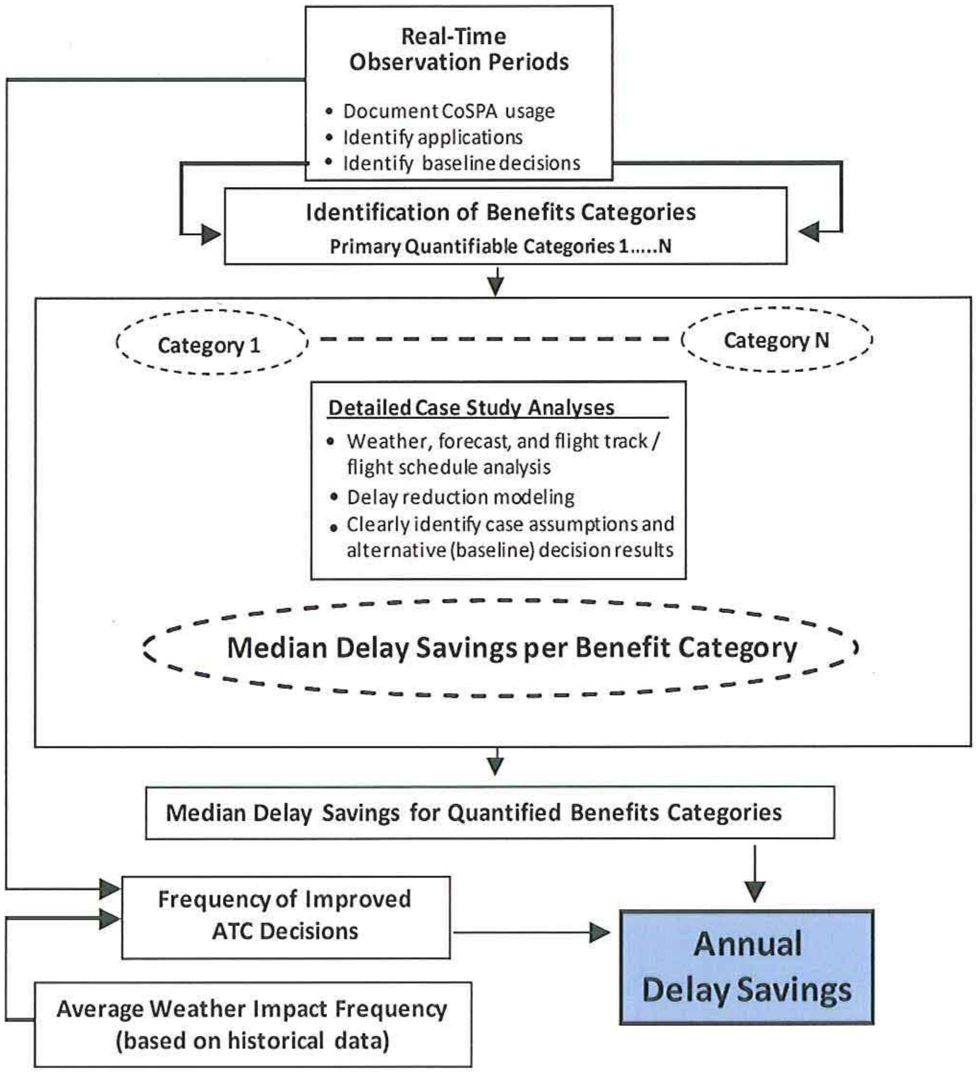

Figure 3-3. Methodology used to estimate annual CoSPA delay savings.

3.3 Estimating Quantitative Delay Savings

3.3.1 Delay Reduction Models

Delay savings attributed to CoSPA usage were achieved both while flights were airborne and while they were still on the ground. In assessing these benefits, delay savings were considered using both linear and queuing delay models.

The linear delay model corresponds to a "transient" event where there is no reduction in the overall average rate of aircraft movement (Robinson et al. 2004). Examples of linear delay benefits include (a) a group of flights avoiding a longer airborne reroute and (b) flights released from an Estimated Departure Clearance Time (EDCT) delay and departing without excessive taxi delay. As described in Robinson et al. (2004), the key element of these types of delays (and delay-modeling exercises) is that the benefit for improved performance is typically "linear" in each of the pertinent variables (e.g., traffic density, ability to realize benefit in a given ATM situation, rate of delay savings over time, etc.).

In estimating CoSPA linear delay savings, the following metrics and assumptions were used:

- Passenger aircraft average block speed: 365 mph (FAA, 2010)
- Average aircraft speed assigned to all flights included in benefits calculations
- Any flights released early from EDCTs (because of beneficial strategic planning

decisions) had only linear delay savings (i.e., no terminal queuing delay savings[2]).

The queuing model for delay reduction estimates is applicable in situations where the weather reduces the effective capacity of an airspace resource (e.g., airport terminal, fix, or jetway) for some finite time while the air traffic demand for that resource is constant and exceeds the weather-reduced capacity. Previous CIWS and RAPT delay reduction benefits studies have demonstrated that both terminal and route-based queuing delays can occur when convective weather impacts occur (Robinson et al. 2004; Robinson et al. 2008). Given the circumstances associated with the observed CoSPA beneficial decision (see Section 4), the queuing model for this study was used primarily for route-based queuing delay scenarios. In these instances and when applicable, a single-server queue model[3] requiring only two input fields (traffic demand and capacity as a function of time) and based on the following equation was used to estimate CoSPA/LCH delay savings:

$\sum$(Delay to individual aircraft) = $0.5\ T^2\ (D - C_w)[(C_v - C_w)/(C_v - D)]$ (Eq. 3-1)

Where D = demand, C_w = capacity during adverse weather, C_v = capacity during benign weather, and T = effective event duration (Andrews, 1993).

In estimating route-based queuing delay savings, the following metrics and assumptions were used:

- Fair-weather route capacity (traffic crossing a waypoint): 30 aircraft / hr[4]
- Adverse-weather route capacity with 30 Miles-In-Trail (MIT) restriction: 10 aircraft / hr
- Adverse-weather route capacity with 40 MIT restriction: 8 aircraft / hr

3.3.2 Converting Hours of Delay to Monetary Estimates

CoSPA delay reduction benefits expressed in hours of delay were converted to airline Direct Operating Costs (DOC) and Passenger Value Time (PVT). The following cost conversions and/or multipliers were used to estimate the total 2010 delay reduction benefits attributed to CoSPA or LCH:

1. 2010 DOC, on-the-ground, at the gate[5]: $967 per hr (FAA, 2010)

2. 2010 DOC, airborne: $4289 per hr (FAA, 2010)

3. Commercial, personal PVT: $23.30 per passenger per hr (FAA, 2010)

4. 2010 avg passengers per aircraft (FAA, 2010): 54 passengers per aircraft
   - [(air carrier capacity * avg load factor) + (air taxi capacity * avg load factor)]/2
   - [(101.2 * .813) +(33 * .757)]/2

5. 2010 PVT: $1258 per hr

6. Downstream delay multiplier:

[2] In an effort to estimate CoSPA delay reduction benefits as conservatively as possible (with the available resources), it was assumed that on-the-ground flights included in the benefits case studies, typically departing for the large airports in the Northeast (e.g., metro NY, metro DC, PHL), did not encounter queuing delays upon departure – or queuing delay savings with shortened or avoided EDCT times (i.e., departure demand at these individual airports did not exceed available capacity). This assumption is assumed to be valid, given historically low air traffic demand in 2010, and, given the nature of most of the on-the-ground benefits case studies, the exclusion of most airports prone to terminal queuing delays (e.g., metro NY airports).

[3] The queuing delay model, developed by Evans (1997), is discussed in detail in Robinson et al. (2004). In 2007, the FAA Simulation and Analysis Team (AJP-6610) independently tested and validated this model, deeming it suitable for weather-ATM benefits experiments.

[4] Robinson et al. (2004) assumed 10 Miles-In-Trail (MIT) as a conservative estimate of aircraft spacing on a jet route outside of terminal airspace during fair weather. Again to be conservative, they also assumed a fast average ground speed (530 mph) for flights included in calculations of route capacity for route-based queuing delay estimates. Together, these values for route usage variables result in the conservative estimate of 30 aircraft per hour on a route. These same input variables were used in the route-based queuing delay estimates in this report.

[5] The 2010 on-the-ground airline DOC for passenger air carriers was $2054/hr. However, this DOC accounts for costs incurred while taxing on the airport surface. Since most on-the-ground delay savings attributed to CoSPA were the result of improved or avoided EDCTs, the at-the-gate DOC metric was recommended as more appropriate (FAA ATO-F, personal communication).

1.57 (Welman et al. 2010)

7. Downstream operating cost savings:
   0

8. Downstream PVT savings:
   0.57 of direct PVT

Calculated downstream delay benefits were also calculated to estimate the ripple effect that arises when an aircraft is delayed on one leg of a flight (e.g., due to adverse weather) such that the subsequent legs flown by that aircraft that day are also delayed (e.g., DeArmon, 1992). In this study, downstream delay reductions are assumed to equal 57% of the initial delay (Welman et al. 2010). Following the rationale described in Robinson et al. (2004), downstream cost savings are estimated only for PVT. The downstream delay savings multiplier used in this study is considered conservative relative to past research in this area (e.g., Hartman, 1993; Beatty et al. 1999; Robinson et al. 2004).

3.4 Determining Annual Delay Savings

With the methodology described in Fig. 3-3, median delay savings per primary benefit category, determined from individual benefits case study results, are multiplied by the annual estimated frequency of occurrence of each benefit type to determine annual CoSPA delay reduction benefits. With this approach, the observed frequency of use for each benefit category at each of the individual facilities is normalized by the total number of observation days to determine the frequency of use per convective weather day (see Section 4.2). Multiplying the normalized benefits frequency by an average annual estimate for weather impact events within the evaluation region provides the annual usage estimates used to "roll-up" per event delay savings to annual benefits results.

Robinson et al. (2006) estimated annual, climatologically-adjusted convective weather days for ARTCCs comprising the Great Lakes and Northeast NAS corridors – ZAU, ZID, ZOB, ZDC, ZNY, and ZBW (see Appendix C of that report). These statistics, along with estimates based on these results for the three additional ARTCCs included in the CoSPA/LCH benefits evaluation (ZMP, ZKC, and ZTL) are presented in Table 3-2. Given that strategic planning decisions made with the aid of strategic weather forecasts (including CoSPA in this evaluation) typically span across multiple ARTCCs, and include coordination with neighboring ARTCCs that may be free of convective weather impacts for the impact day in question, the average number of estimated, annual convective weather days for all 9 ARTCCs (**95**) was considered the approximate number of days per year on which identified CoSPA or LCH benefits categories could be achieved.

One of the identified CoSPA benefits application (see Section 5) that is unique and the exception – where the estimated annual number of days in which the opportunities to consider the decision is far less than 95 days – was when the forecast was used for improved Airspace Flow Program (AFP) execution and management. Historically, when considering the use of this strategic planning initiative for weather impacts during the summer months, convective weather impacts would typically:

- Impact multiple ARTCC in the Eastern NAS
- Cover (or were predicted to cover) large air traffic areas
- Develop and mature during mid-late afternoon, when en route traffic disruptions would be most significant
- Specifically impact en route ZOB and ZDC airspace, west and south of the NY TRACON (N90)

For weather impact mitigation, the primary AFPs that have typically been used are Flow Constrained Area (FCA) A05, A06, A08, and OB1[6]. For 2007, 2008, and 2010 (years for which historical AFP usage data were available), these AFPs were used 44 times per year, on average. If one assumes that an AFP was considered but not used on an additional 25% of the total annual implementation days, then **the total numbers of "AFP-consideration" days per year equals 55.** This was the metric used in this analysis to scale up the daily, normalized CoSPA AFP benefits frequency of use to the estimated annual frequency of occurrence.

[6]Graphical depictions of the pre-determined AFPs can be found at:
http://www.fly.faa.gov/What_s_New/AFPs.ppt

Table 3-2
Estimated Annual ARTCC Convective Days, Accounting for Climatology *

ARTCC	Annual Convective Weather Days
ZAU	110
ZID	100
ZOB	90
ZDC	100
ZNY	65
ZBW	65
ZMP **	100
ZKC **	110
ZTL **	120
Average	**95**

**Statistics from Robinson et al. (2006), rounded down to nearest multiple of 5*

***ZMP, ZKC, and ZTL estimated based on annual convective weather days at nearby ARTCCs (e.g., ZAU, ZDC) and known tendencies for more (ZKC, ZTL) or less (ZMP) convection compared to the neighboring airspace.*

4. COSPA BENEFITS EVALUATION RESULTS

CoSPA operational benefits were identified directly from real-time observations of the usage of these weather forecasts and traffic management decision-making at all visited FAA and airline facilities during the 2010 summer storm season. From the observational data:

- CoSPA benefits categories were identified
- CoSPA frequency of beneficial decisions was identified
- CoSPA delay savings case studies were conducted
- CoSPA annual (2010) delay savings estimates were made

4.1 COSPA Benefits Categories

Usage of CoSPA by FAA traffic managers and airline dispatch coordinators was partitioned into 23 different benefits categories, shown in Tables 4-1 and 4-2. Benefits categories listed in Table 4-1 are strategic planning actions derived from CoSPA forecasts that can directly result in delay savings. They are therefore considered quantifiable benefits. Benefits categories listed in Table 4-2 are impact awareness and planning support applications derived from CoSPA usage, and are considered, at this time, to be more qualitative benefits. It is important to note that an observed CoSPA application was not assigned a benefits category if the forecast was used to assist with decisions in the 0 – 2 hour forecast period (i.e., "tactical" planning period). Only unassisted strategic planning applications, using the 2 – 8 hour CoSPA forecast, were considered CoSPA benefits in this study.[7]

The three primary CoSPA benefits categories, in terms of observed frequency of beneficial decisions (see Section 4.2) and the potential for delay reduction, were AFP, EPB, and ERP (improved Airspace Flow Program management, enhanced Playbook reroute management, and enhanced strategic reroute planning). These three categories were the focus of the 2010 CoSPA delay savings estimates. CoSPA-derived delay-saving decisions involving other quantifiable benefits categories were also evident, but in an effort to remain conservative when estimating CoSPA benefits, case study results for these other categories were not included in the final delay savings estimates.

Many of the other CoSPA benefits categories listed in Table 4-1 pertained to strategic routing decisions for individual flights, city-pairs, and airlines (e.g., ITR, RIF, MIL, and AFM). Moreover, many of these CoSPA-derived beneficial decisions were observed being made by ATC coordinators and dispatchers at Airline Operations Centers (AOCs), such as Continental and United.

Though more difficult to translate into tangible delay and cost savings estimates, the CoSPA benefits categories listed in Table 4-2 are considered critical to improved strategic planning and enhanced collaborative decision-making during convective weather events. CoSPA contributions to improved awareness, coordination, and collaboration can increase the likelihood of implementing other CoSPA-derived capacity enhancement decisions such as ERP or AFP.

[7] The reason for this is that the tactical ATM benefits of the CIWS 0 – 2 hour Precipitation and Echo Tops forecasts, which are scheduled to be operationally available to all traffic managers via the Traffic Flow Management System in 2011, have already been evaluated (e.g., Robinson et al. 2004).

Table 4-1
Observed CoSPA Benefits Categories (Quantifiable)

KEY	CoSPA BENEFIT CATEGORY
*AFP	**Improved AFP Execution / Management** *(assigned when CoSPA used to make AFP Go/No-Go decisions, AFP decisions on start time, stop time, rate, plan modifications, etc.)*
GDP	**Improved Ground Delay Program Execution / Management** *(only assigned when decision made to explicitly avoid GDP, to implement GDP, to modify rate/scope, or to end GDP, based on CoSPA)*
GS	**Improved Ground Stop Execution / Management** *(only assigned when decision made to explicitly avoid GS, implement a GS, modify scope or end time of GS – based on CoSPA)*
*EPB	**Enhanced Playbook Reroute Planning and Execution** *(explicit action to execute, modify, or avoid a Playbook routing based on CoSPA)*
*ERP	**Enhanced Reroute Planning** *(includes avoiding reroutes by recognizing viability of nominal routes, proactive reroute implementation, and ending reroutes/returning to nominal routes sooner, etc.)*
MRR	**Improved Management of Route Restrictions** *(includes MIT restriction, management on nominal routes)*
MIL	**Improved Strategic Management Decisions in Support of Military Air Traffic**
ITR	**International Traffic Routing Assistance** *(explicit routing decisions for international traffic flows or individual flights to/from international destinations)*
RIF	**Strategic Routing Assistance for Individual Flights or city-pairs**
AFM	**Airline Fleet Management Assistance** *(includes decisions on airline-only ground stops, cancellation (or cancellation avoidance) decisions, support in issuing airline Planning Alert Messages (PAM), etc.)*
ICR	**Improved Integrated Collaborative Reroute (ICR) Program execution and management**
DOP	**Departure Operations Planning Assistance (Large TRACONs)**
RCM	**Proactive Runway Configuration Management**
TMA	**Enhanced Planning for Airport Arrival Metering (TMA)**

** Primary quantifiable benefits category*

Table 4-2
Observed CoSPA Benefits Categories (Impact Awareness and Planning Support)

KEY	CoSPA BENEFIT CATEGORY
SPD	**Assistance with Strategic Plan Development**
SP-CCFP	**Use of CoSPA in concert with CCFP for enhanced weather impact awareness**
CWSU	**Support for CWSU, SCC Weather Unit, or NWS operations in support of ATM**
I/IC	**Enhanced Inter/Intra-Facility Coordination**
STAFF	**Assistance with facility staffing decisions;** Proactive Monitor Alert Threshold (MAP) limit adjustments (aid sector controllers)
EQUIP	**Assistance with ATC equipment management decisions**
SA-R	**Enhanced Situational Awareness – Route (En Route Airspace) Impact Monitoring**
SA-T	**Enhanced Situational Awareness – Terminal Impact Monitoring**
SA	**General Situational Awareness**

In addition to direct traffic management support applications (e.g., SPD, SA categories), benefits categories listed in Table 4-2 demonstrate the additional ATM-support applications of CoSPA that were observed during the field evaluations. One of the more significant findings was that ARTCC Center Weather Service Unit (CWSU) meteorologists were frequently observed using CoSPA precipitation and echo tops forecasts to assist with their tasks that ranged from CCFP collaboration and development, to monitoring issued convective weather Significant Meteorological information (SIGMET) advisories, to direct input to traffic managers about potential terminal or en route weather impacts (or predictions for improving conditions).

Another interesting observed CoSPA "support application" pertained to proactive staffing decisions. Examples of these benefits included:

- ensuring that specific sectors, predicted by CoSPA to be impacted by weather, would have adequate (and sometimes extra) controllers on position,
- timing breaks and position rotations in an ARTCC Traffic Management Unit (TMU) to support opening the "severe weather" position when CoSPA predicted weather impacts would become significant, and
- proactively modifying Monitor Alert Parameter (MAP) thresholds, based on CoSPA predictions for sector impacts, to ensure demand would be in line with expected capacity constraints and controllers working that sector would not be overloaded.

4.1.1 Examples of Improved Strategic Planning Benefits Attributed to CoSPA

During the 2010 field evaluation, operational decision-makers were observed repeatedly using CoSPA to deliberate about the need for and the specific parameters of Airspace Flow Programs (AFP) and strategic reroutes [both with and without the use of coordinated Playbook routings (EPB and ERP benefits categories)]. Strategic planners would use the deterministic precipitation forecast (on occasion, the CoSPA echo tops forecast was also consulted) to more specifically identify the coverage, location, and organization-type [e.g., line (solid or broken – and if broken, were the gaps usable for traffic flows), clusters, or cellular convection] of anticipated weather impact events. Operational users were able to use this information to better define the severity of impacts within broader, less-defined CCFP polygons (which were typically "low coverage, low confidence" predictions).

Users also found the rapid update rate of CoSPA to be a positive forecast attribute when assessing the need and scope for strategic planning initiatives. The availability of new, rapidly-updating CoSPA forecast information proved to be important for strategic planning, given that traffic managers (ARTCCs) and National Traffic Management Officers (NTMOs at the ATCSCC) were observed (during the morning hours) exerting the most time and effort assessing the potential severity and possible solutions for anticipated weather impact events during the 30-45 min period <u>prior</u> to the bi-hourly Strategic Planning Telecoms (SPT) – when available CCFP forecasts were 90-105 min old![8]

Through these uses of CoSPA, many decisions were made in support of AFP, Playbook, and strategic reroute execution and management. Specifically, aviation planners were observed using CoSPA to aid with decisions on the need, timing, rate, scope, duration, and/or cancellation of AFP, EPB, and ERP strategic planning initiatives. An example of CoSPA usage for AFP decision-making is illustrated in Figure 4-1. During this event, ATCSCC National Traffic Management Officers (NTMO) used the CoSPA forecast – predicting only widely scattered level 3+ precipitation across the Northeast NAS (airspace being controlled by an AFP A05 program) over the next 2 – 6 hours – to make the decision to cancel the AFP program early. Interestingly, this CoSPA-derived decision was made despite the CCFP 2-hr and 4-hr forecasts that were available at that time predicting significant convection in the metro NY to DC air traffic corridor (see Fig. 4-1A). By cancelling this AFP program early, 58 flights scheduled to fly through AFP airspace had their planned departure delays or longer reroutes

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[8]Observations that critical strategic planning assessments and collaboration were often conducted just prior to the SPTs, when the "valid" CCFP forecasts were most obsolete, suggest that the timing for when CCFP forecasts are developed and published may need to be revisited. Without up-to-date CCFP forecasts available during their critical plan development period, ATCSCC NTMOs were often observed peeking over the shoulder of weather specialists in order to read ongoing CCFP chat logs and to get a preview-glance of the "next" CCFP forecast – with the CCFP polygons still under negotiation.

cancelled, allowing for considerable delay savings (Fig. 4-1B).

Many of the other CoSPA benefits categories listed in Table 4-1 pertained to strategic routing decisions for individual flights, city-pairs, and airlines (e.g., ITR, RIF, MIL, and AFM). An example of a proactive, strategic reroute decision made for an individual flight using CoSPA forecasts is shown in Figure 4-2. In this case, significant convection was already impacting the planned route of an international flight about to enter U.S. airspace (Fig. 4-2A). ZBW began coordinating with neighboring facilities on reroute options. At first, a reroute option through the TN valley was considered (white box in Fig. 4-2B), but then ZBW, ZNY, ZDC, and ATCSCC collectively used the CoSPA precipitation forecast to identify a viable reroute corridor through gaps in convection along the East Coast (Fig. 4-2B). The international flight was able to utilize this reroute without any issues (see Figs. 4-2C and 4-2D).

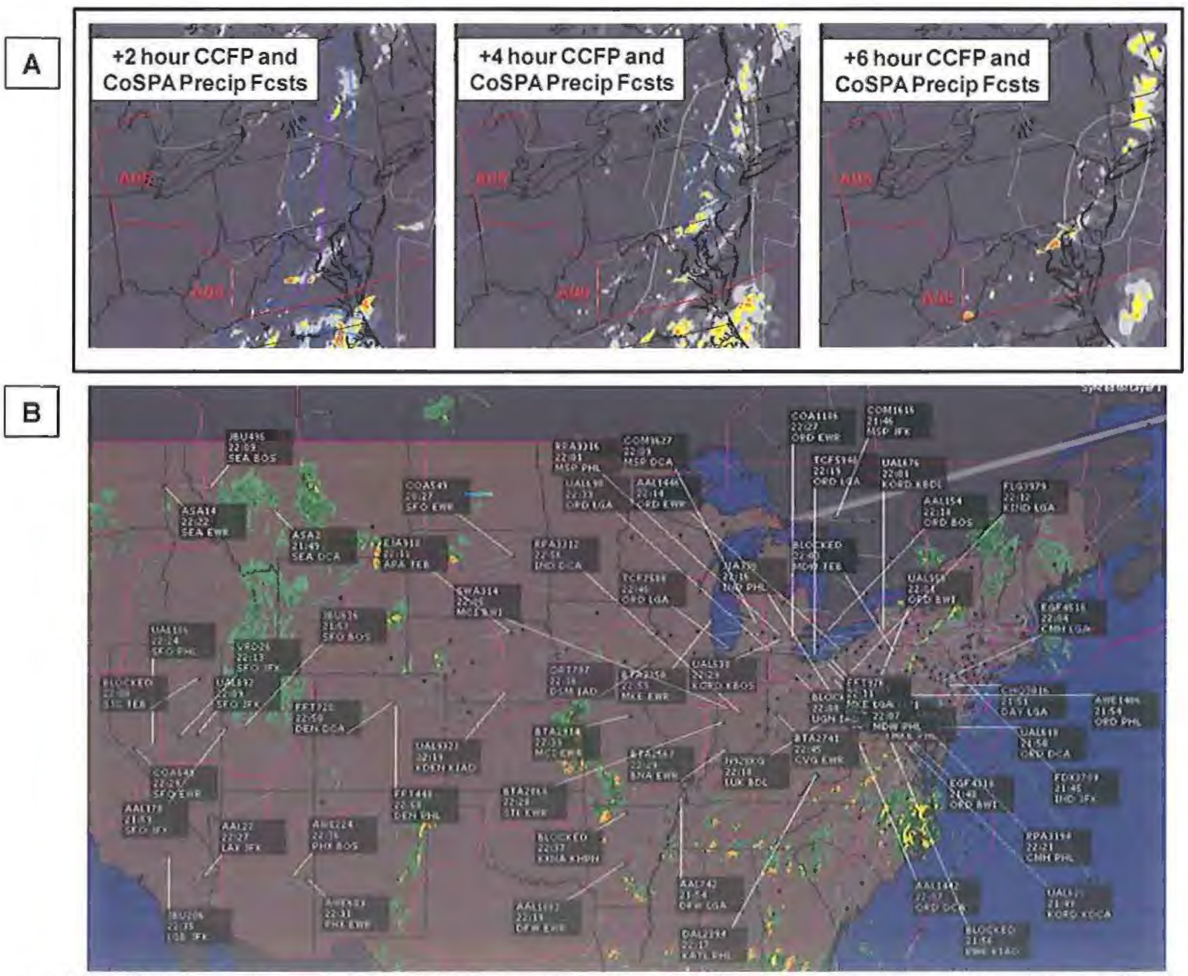

Figure 4-1: (A) 2-hr, 4-hr, and 6-hr CoSPA precipitation and CCFP forecasts at 2140 UTC on 16 June 2010 - CoSPA/CCFP forecasts valid for 2340/2300 UTC, 0140/0100 UTC, and 0340/0300 UTC. (B) Flight Explorer weather depiction and flight tracks at 2305 UTC on 16 June 2010 showing flights (with tags) that were released early from Estimated Departure Clearance Time (EDCT) delays and/or elected to not use CAN 7 EAST reroute, when AFP A05 was cancelled early.

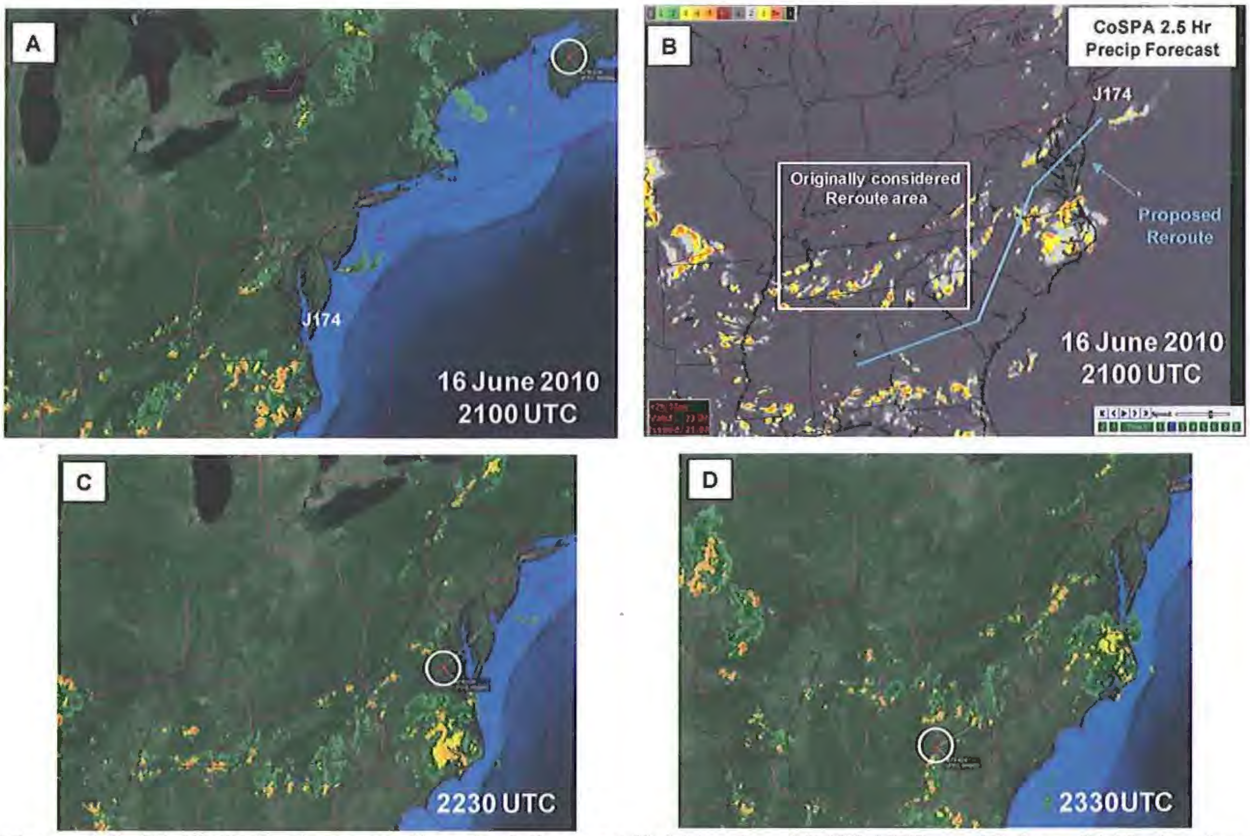

Figure 4-2. (A) Flight Explorer weather depiction and flight tracks at 2100 UTC on 16 June 2010 showing an international flight, AFR434 to Mexico City, entering ZBW and its filed route, using J174, blocked by convection. (B) CoSPA 2.5-hr precipitation forecast issued at 2100 UTC predicts a viable reroute corridor for AFR434 through gaps in convection along the East Coast (blue line). Flight Explorer flight tracks at (C) 2230 UTC and (D) 2330 UTC show that AFR434 was able to successfully utilize this reroute.

4.1.2 Insufficient Situational Awareness or Strategic Decisions Resulting from Use of Inaccurate CoSPA Forecasts

Overall, operational decisions made based on CoSPA 2 – 8 hr forecasts resulted in more efficient strategic planning initiatives that helped reduce air traffic delay (see Section 4.3). However, in some instances, inaccurate precipitation or echo tops predictions from this prototype forecast led to impaired situational awareness and at times, poor strategic planning decisions.

Figure 4-3 and 4-4 illustrate an example of a poor planning decision made with CoSPA. During this event (02 Sep 2010), ZMP used the CoSPA 2 – 4 hr precipitation forecast, which showed continued convective weather impacts in southeast ZMP airspace (affecting the MSP southeast arrival flow), to argue for the implementation of the MSP_KASPR_EAU Playbook until 1500 UTC (the next 4 hours). ATCSCC was against this plan, but ZMP used CoSPA as evidence that the Playbook was needed – and at the time of this decision, the CCFP forecast was almost 2 hours old (see Fig. 4-3).

Unfortunately, the CoSPA forecast over-predicted the coverage and severity of convection southeast of MSP (Fig. 4-4D). The convective weather moved quickly northeast, out of this region, and thus MSP arrivals from the southeast were forced to fly unnecessarily long routes. Moreover, with one MSP arrival cornerpost closed, arrival demand exceeded capacity for a time at another cornerpost, causing some additional airborne holding (Fig. 4-4B).

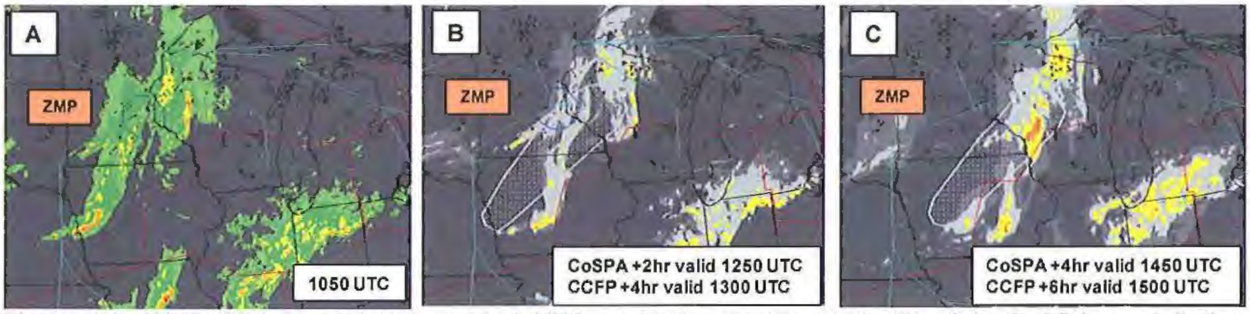

Figure 4-3. (A) CoSPA precipitation at 1050 UTC on 02 September 2010, (B) +2-hr CoSPA precipitation (and +4-hr CCFP) forecasts valid 1250 (1300) UTC, and (C) +4-hr CoSPA precipitation (and +6-hr CCFP) forecasts valid 1450 (1500) UTC. Blue lines show the MSP_KASPR_EAU Playbook implemented for MSP arrival traffic (1050 – 1500 UTC) based on the CoSPA prediction for ongoing convection southeast of MSP airport.

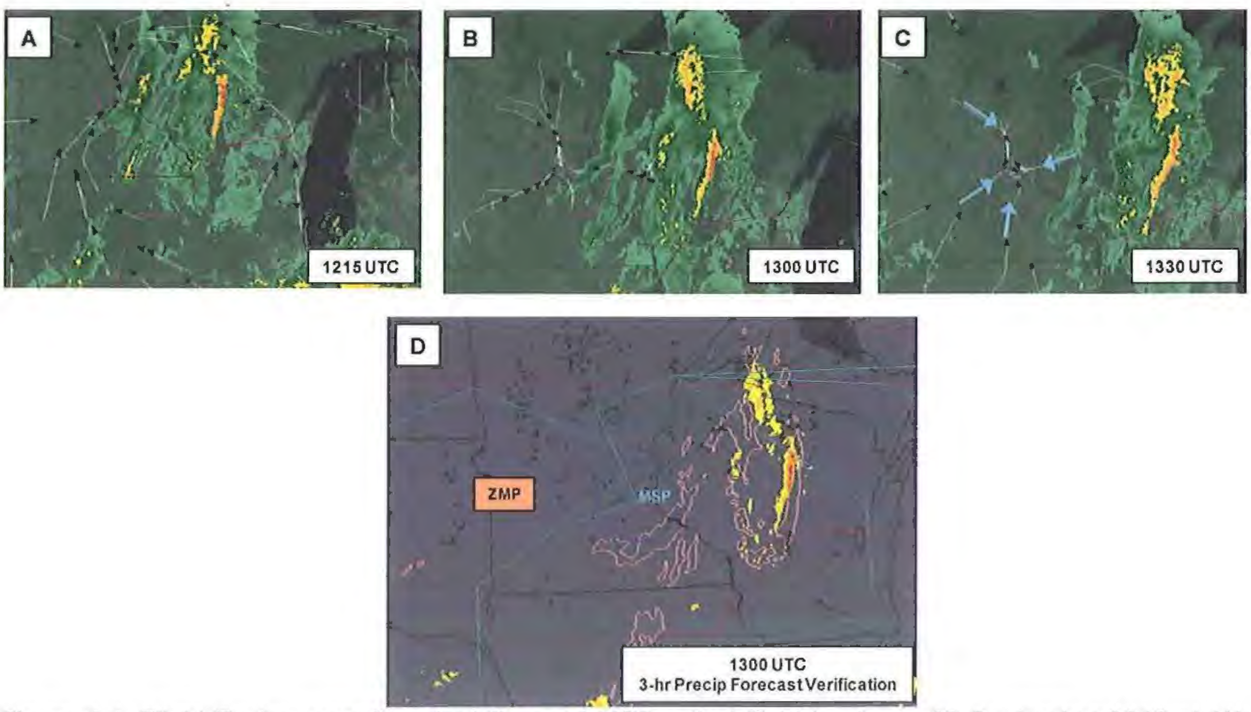

Figure 4-4. Flight Explorer weather depiction and MSP arrival flight tracks on 02 September 2010 at (A) 1215 UTC, when the MSP Playbook was in effect, (B) 1300 UTC, when airborne holding occurred as demand for available arrival fixes exceeded capacity, and (C) 1330 UTC, when the four arrival flows reopened early. (D) The 3-hr CoSPA precipitation forecast verification contour, compared with level 3+ "truth" precipitation, shows that the large area of convection predicted southeast of MSP at 1300 UTC did not occur.

Observers were not explicitly tasked with documenting CoSPA-derived decisions that proved to be less efficient than the likely baseline or alternative decision. In fact, it is difficult to determine whether a particular CoSPA application decreased operational effectiveness of strategic planning without the benefit of post-evaluation data analysis. Limited resources precluded a robust analysis of potential "negative" applications of CoSPA.

Instances where inadequate decisions would be made based on CoSPA were not unexpected. The version of CoSPA that was evaluated in 2010 was not the full-capability forecast that is envisioned. Namely, it is understood, for example, that decisions based on CoSPA will improve, and delay reduction benefits attributed to CoSPA (see

Section 4.3) will likely increase, when the deterministic forecast is complemented by a probabilistic forecast component and explicit measures or depictions of forecast uncertainty. Additionally, researchers at multiple laboratories continue to research and develop improvements to the extrapolation, numerical model, and blending components of the CoSPA forecast.

4.2 Frequency of COSPA Beneficial Decisions

The frequency of CoSPA benefits observations at each facility, normalized by the number of convective weather days on which observations were made is shown in Table 4-3. Several interesting (but not unexpected) findings are evident with these results:

- Overall CoSPA usage (including consultation for enhanced situational awareness and decision coordination) was more frequent for EAST weather impact events, as convection in the Northeast NAS quadrant typically causes greater congestion impacts requiring more intervention and strategic planning initiatives.
- CoSPA usage was most frequent at "SCC" (Command Center), the facility charged with overall strategic plan development, execution, and management. In terms of individual benefits categories, ATCSCC most frequently used CoSPA in support of AFP, Playbook routes, and strategic rerouting decisions. Additionally, ATCSCC was much more active in using CoSPA for improved situational awareness, for improved impact definition within CCFP polygons (SP-CCFP), and for enhanced inter/intra-facility coordination (which again, is not surprising given that the ATCSCC often facilitates strategic planning decisions between various FAA facilities and airline stakeholders). In fact, the observed daily use of CoSPA for situational awareness applications was similar to the observed daily use of other demonstration tools (i.e., CIWS and RAPT) in their second or third year of testing, when users had increased familiarity and "comfort" with the new technology [e.g., Robinson et al. (2006); Robinson et al. (2009)]. This suggests that more applied applications of CoSPA for explicit strategic plan development may be expected in any follow-up evaluations, as users translate more situational-awareness-type applications directly into improved weather impact mitigation decisions [Robinson et al. (2011)].
- ZOB was the most active EAST ARTCC in terms of using CoSPA to aid with AFP, Playbooks, and strategic reroute decision-making (AFP, EPB, and ERP). Again this was not surprising, since ZOB is a key en route center for strategic planning when adverse weather impacts the Northeast.
- The airline ATC coordinators and dispatchers (particularly COA and UAL) were active in using CoSPA to strategically plan routes around weather for individual flights or city-pairs, as well as make decisions about the need for "company-only" airport Ground Stops or terminal management initiatives ('AFM' benefit category). The airlines also most frequently used CoSPA to monitor potential terminal impacts (e.g., EWR, ORD, ATL, IAH) in the 2 – 8 hr strategic time period ('SA-T' category). Moreover, the airline AOCs also most frequently used CoSPA to better prepare departure operations at specific airports (primarily metro NY) – proactively asking for NY departure "escape routes", the availability of departure offload routings, etc. ('DOP' category).
- Overall CoSPA usage at ZNY was minimal. This result was not completely surprising given that strategic planning for weather impacts in the Northeast NAS quadrant is inherently set up to sufficiently manage air traffic upstream of ZNY, given that (a) ZNY's small, congested airspace affords little opportunity for planned impact mitigation actions (beyond increased route spacing) and (b) the greater need of ZNY is to maximize tactical (0-2 hr) opportunities for weather impact mitigation. In other words, with weather in the Northeast NAS quadrant, many strategic actions are being taken by other facilities *for* ZNY, reducing the need for ZNY to use CoSPA to devise additional strategic plans.
- Across all facilities, use of CoSPA for enhanced planning, execution, and management of Ground Delay Programs (GDP) was low. This may have been due to a combination of factors such as (a) timing and frequency of thunderstorm events at large terminals or metroplexes

(e.g., metro NY, metro DC, ORD, ATL) and (b) lack of user confidence in the new forecast for such specific strategic planning decisions. The ability of CoSPA to accurately and consistently resolve local storm impacts 2 – 8 hours in the future on the spatial scale of a terminal or TRACON may also have been ill-suited without some additional information about forecast uncertainty.

The frequency of observed CoSPA beneficial decisions per convective weather day for all EAST and MIDWEST facilities is shown in Figure 4-5. Across both evaluation regions, AFP, EPB, and ERP CoSPA applications were the most prevalent "quantifiable" benefits categories – and were therefore considered the primary decisions upon which CoSPA delay savings estimates were based (see Sections 4.3 and 4.4). CoSPA usage at EAST facilities for enhanced Departure Operations Planning (DOP) in the 2-8 hr time period was also quite frequent, but DOP cases were not considered for delay savings calculations since most of these observed uses were more qualitative in nature (e.g., asking for availability of departure offload routes 3-6 hours before they will be needed), and thus delay reduction benefits were more difficult to estimate.

Table 4-3
Normalized CoSPA Benefits Observations by Facility for (A) EAST and (B) MIDWEST Evaluations**

A	SCC	ZOB	ZDC	ZTL	ZBW	ZNY	ZID	N90	Airlines
AFP	1.2	0.7	0.2	0	0	0	0	0	0
GDP	0.1	0.1	0	0	0	0.1	0	0	0
GS	0	0.1	0	0	0	0	0	0	0.1
EPB	1.7	1	0	0.3	1	0	0.5	0	0.7
ERP	2.2	1	0.4	0.5	1	0.1	0.3	0	1.2
MRR	0.1	0.2	0.1	0	0.3	0	0	0	0.1
MIL	0	0.2	0	0	0	0	0	0	0
ITR	0.1	0.1	0	0	0.1	0	0	0	0.1
RIF	0.1	0	0	0	0.4	0	0	0	0.4
AFM	0	0.1	0	0	0	0	0	0	0.8
ICR	0.1	0	0	0	0	0	0	0	0
DOP	0.7	0.1	0.1	0	0.3	0.4	0.1	0.3	1.2
RCM	0	0	0	0	0	0	0	0.3	0
TMA	0	0.5	0	0.1	0.1	0	0	0	0
#WX Days	9	9	9	8	8	8	8	6	9
SPD	5.8	2.2	0.4	0.7	1	0.1	0.1	0.5	0.9
SP-CCFP	1.6	2	0.4	0.7	0.8	0.1	0.5	0	1.4
CWSU	0.4	0	0	0.7	1.6	0.4	0	0	0.2
I/IC	9.1	5.2	1.2	3.7	8.4	0.8	1.5	1.3	3.7
STAFF	0	0.1	0	0.1	0	0	0	0.3	0
EQUIP	0	0	0	0	0	0	0	0.1	0
SA-R	15.2	11.2	2.1	6	9.9	1	3.6	1.5	7.2
SA-T	5.6	5.2	0.7	4	0.8	0.6	1.1	3.2	5.8
SA	3.1	2.7	1	3.6	3.6	0.9	3	2	5.9

B	SCC	ZMP	ZAU	ZKC	C90	Airlines
AFP	0	0	0	0	0	0
GDP	0.2	0	0	0	0	0
GS	0	0	0	0	0	0
EPB	0.7	0	0.5	0.4	0	0.2
ERP	0.5	0.5	0.7	0.4	0	0
MRR	0	0.3	0	0	0	0
MIL	0	0	0	0	0	0
ITR	0	0	0	0	0	0
RIF	0	0.3	0	0	0	0.3
AFM	0	0	0	0	0	0.5
ICR	0	0	0	0	0	0
DOP	0	0	0	0	0	0
RCM	0	0	0	0	0	0
TMA	0	0	0.2	0	0	0
#WX Days	6	4	6	5	4	6
SPD	0.2	0.5	0.7	0.2	0	0.3
SP-CCFP	0.8	0.8	0.5	1	0	0.2
CWSU	0.5	1	1	0.8	0	0
I/IC	3.5	6.3	2.5	4.4	1.3	2.8
STAFF	0	0	0.3	0.2	0	0
EQUIP	0	0	0	0	0	0
SA-R	5.8	5.5	3.5	2.4	0.5	4
SA-T	2.8	1.5	1.7	1.4	3.5	3.2
SA	4.3	6	3.8	10	9	6.8

****Facility that used CoSPA most frequently for each benefit category is shown in GREEN*

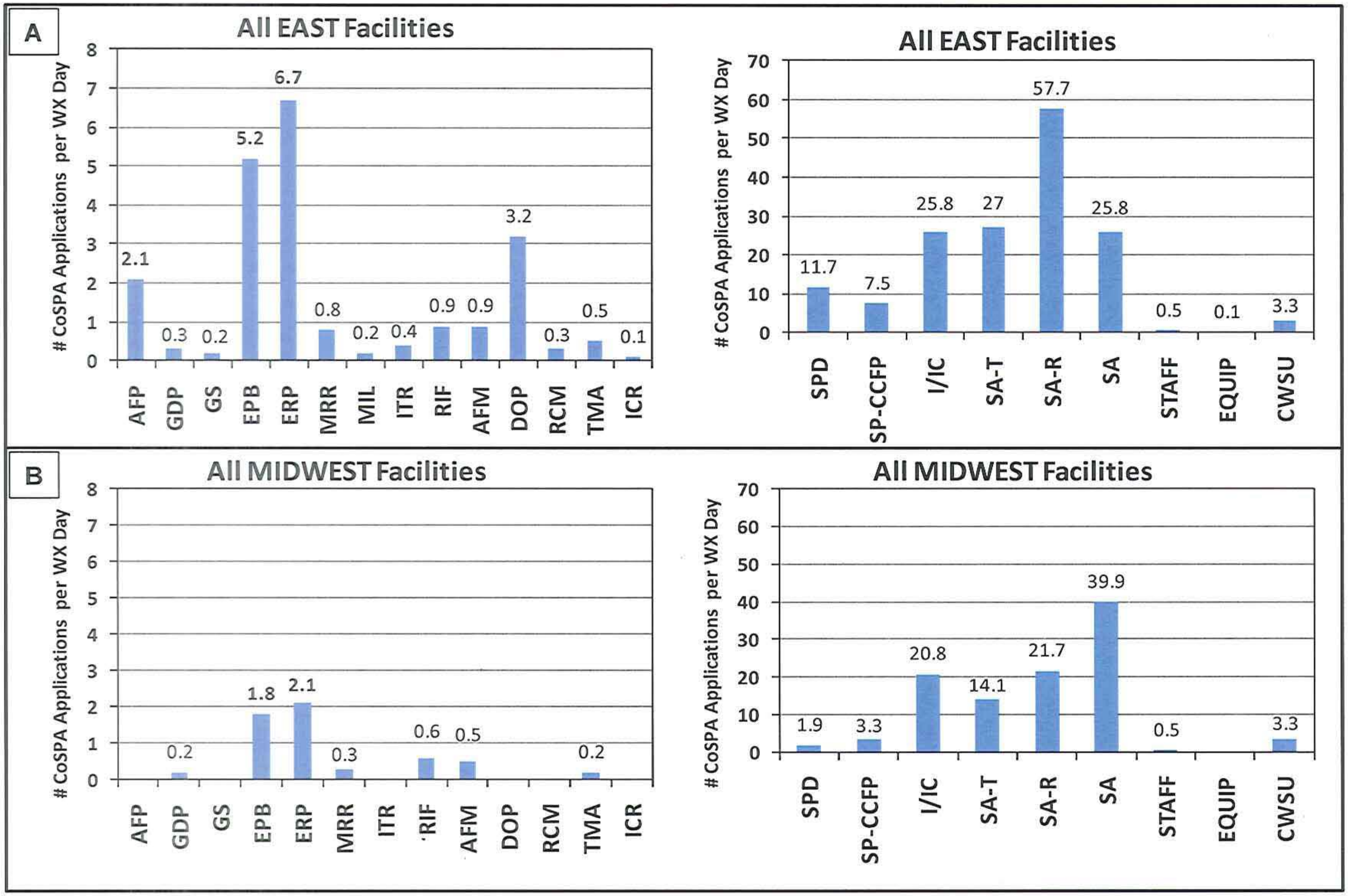

Figure 4-5. Frequency of observed CoSPA benefits per convective weather day for all EAST and MIDWEST facilities.

4.3 COSPA Delay Savings Case Studies

Case studies of observed CoSPA operational usage were analyzed to estimate the delay savings associated with the three primary strategic planning benefits categories – AFP, EPB, and ERP. To prevent double-counting, care was taken when categorizing CoSPA usage observations to ensure that one primary benefit category was assigned to each documented application (e.g., if a strategic rerouting application was categorized as EPB, then it could not also be categorized as ERP – and vice versa).

A total of 15 CoSPA benefits cases were analyzed – 5 cases for each primary benefits category. Cases were arbitrarily selected in a manner that allowed us to sample beneficial decisions and examine potential delay reduction benefits across as many different facilities and airspace regions as possible. A summary of case study results from one AFP, EPB, and ERP decision derived from CoSPA is presented in Tables 4-4 – 4-6, respectively.

Table 4-4. Summary of CoSPA Benefits Case Study for Improved AFP Decision-Making

Date:	19 July 2010
Facilities Using CoSPA:	ZDC
CoSPA Application:	Upon reaching decision to implement AFP A08, ZDC used CoSPA 3 – 5 hr precipitation forecasts – predicting minimal Northeast convective weather development prior to 1900 UTC – to convince ATCSCC to start AFP at 1900 UTC rather than 1700 UTC.
Alternative Decision:	Without CoSPA, AFP A08 likely would have started at 1700 UTC; 1300 UTC 4 hr CCFP predicted low confidence, low coverage polygon through central ZDC at 1700 UTC – historically, this type of CCFP forecast has proven sufficient justification for A08 implementation.
Benefit Period:	1700-1900 UTC (2.0 hr)
CoSPA Delay Savings Calculations:	
A08 Program: 1900 – 0200 UTC (issued 1445 UTC) Rate: 90 flights/hr Avg Delay: 16 min Total flights departing for primary A08 airports between 1700-1900 UTC AND crossing A08 boundary that would have received AFP EDCTs, averaging 16 min delay:	141
Primary delay reduction for 141 departures avoiding 16 min AFP delay:	37.6 hr
Downstream Delay Reduction:	21.4 hr
Total CoSPA Delay Reduction:	**59.0 hr**
Direct Operating Cost (DOC) Savings:	$36,359
Passenger Value Time (PVT) Savings:	$47,301
Downstream Cost Savings (PVT only):	$26,921
Total CoSPA Cost Savings:	**$110,581**

Table 4-5. Summary of CoSPA Benefits Case Study for Enhanced Playbook Route Management (EPB)

Date:	14 June 2010	
Facilities Using CoSPA:	ZID	
CoSPA Application:	ZID used CoSPA precipitation forecast (as additional information to augment CCFP) to determine that an eastward moving cluster of storms was predicted to hold together and impact ORD arrivals through ZID airspace. Based on CoSPA, ZID proactively collaborates on a Playbook reroute plan – "ORD-East-Arrivals" modified Playbook route implemented 2055-0100 UTC – allowing a single stream of ORD arrival traffic through ZID airspace	
Alternative Decision:	Without CoSPA, ZID likely would not have readily anticipated the functional gaps in forecast weather within the large, high-confidence CCFP forecast region. In turn, single stream ORD arrival flows over MZZ/FWA (part of modified Playbook routing) likely would have instead routed further west to the FAM fix or further north via FWA (rather than using MZZ)	
Benefit Period:	2055 – 2347 UTC (2.9 hr)	
CoSPA Delay Savings Calculations:		
Number of ORD arrival flights, departing during benefits period, utilizing MZZ or FWA leg of Playbook routing:		12
Total flight distance saved:		1450 mi
Primary delay reduction:		4.0 hr
Downstream Delay Reduction:		2.3 hr
Total CoSPA Delay Reduction:		**6.3 hr**
Direct Operating Cost (DOC) Savings:		$17,156
Passenger Value Time (PVT) Savings:		$ 5,032
Downstream Cost Savings (PVT only):		$ 2,893
Total CoSPA Cost Savings:		**$25,081**

Table 4-6. Summary of CoSPA Benefits Case Study for Enhanced Strategic Management of Air Traffic Reroutes (ERP)

Date:	07 July 2010
Facilities Using CoSPA:	ZMP
CoSPA Application:	At approximately 1500 UTC, ZMP area supervisor wanted to stop the NW arrival flow to ORD through the southeast ZMP sectors because of convection along the ZAU/ZMP border. The STMC viewed CoSPA forecasts – which predicted storms continuing on this region but weakening below 30 kft with time (+3 hr and beyond) – and convinced the area supervisor to keep the nominal route open.
Alternative Decision:	Without CoSPA, the GEP (northwest) ORD arrival flow would have been rerouted south, to the westerly arrival flow, per the area supervisor's request
Benefit Period:	1515-1815 UTC (3.0 hr)
CoSPA Delay Savings Calculations:	
Number of ORD flights flying nominal ZMP-GEP (northwest) arrival route and avoiding reroute to the south:	8
Total flight distance saved:	784 mi
Primary delay reduction:	2.1 hr
Downstream Delay Reduction:	1.2 hr
Total CoSPA Delay Reduction:	**3.3 hr**
Direct Operating Cost (DOC) Savings:	$ 9,007
Passenger Value Time (PVT) Savings:	$ 2,642
Downstream Cost Savings (PVT only):	$ 1,510
Total CoSPA Cost Savings:	**$13,159**

A summary of CoSPA delay savings (hours of delay saved and cost savings) derived from all of the cases studies, for each of the three primary benefits categories, is provided in Tables 4-7A – 4-7C. The calculated delay reduction for individual beneficial strategic decisions derived from CoSPA ranged from 3.3 hours (07 July 2010 – ERP case) to 145.5 hours (20 July 2010 – AFP A08 case). Case-to-case variability in delay savings followed expected trends, with the largest benefits being associated with AFP improvements (AFPs are longer, more encompassing strategic initiatives that can affect many more aircraft) and the smallest benefits being associated with enhanced reroute planning (ERP), typically affecting the fewest aircraft in the 2 – 8 hr decision period. Moreover, benefits associated with Playbook reroute enhancements (EPB) were anticipated to be greater than ERP benefits, since the former typically affect more aircraft than the latter.

The results from one case study – 14 June 2010 ERP case – yielded no strategic ATM delay savings (see Table 4-7C). Inspection of this case reveals that though the 2 – 3 hour (i.e., strategic) CoSPA forecasts were used to identify a reroute of ATL arrival traffic from the Northeast through ZID airspace, only three aircraft that were already airborne and within two hours of arriving at ATL (even when using the new route) utilized the route. Since the CoSPA forecast was used to manage only a *tactical* decision – and no other airborne flights or additional flights waiting to depart used the CoSPA-identified ZID reroute – the strategic benefits for this decision were estimated to be zero. Since this case was arbitrarily selected, and the observed CoSPA application was categorized as 'ERP', the results were included with the other ERP case study results, to represent other potential CoSPA benefits cases that may, upon closer inspection, yield little or no strategic planning benefits.

Median CoSPA delay savings per primary, quantified benefits category were computed to determine the average delay reduction per CoSPA application (Table 4-8). Mean delay estimates are likely the most appropriate measure for average delay but given these small case study sample sets, and the degree of spread between some benefits estimates, high variability exists with the mean. Therefore, median benefits results were preferred for estimating annual CoSPA savings.

Table 4-7A

CoSPA Benefit 1: Improved Development, Execution, and Management of Airspace Flow Programs (AFP)

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**AFP**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**Total**
16 Jun	A05	36.5	20.8	57.3	40,943	45,917	26,166	113,026
19 Jul	A08	37.6	21.4	59.0	36,359	47,301	26,921	110,581
20 Jul	A08	92.7	52.8	145.5	89,641	116,617	66,422	272,680
21 Jul	A05	24.7	14.1	38.8	23,885	31,073	17,738	72,696
05 Aug	A05	23.6	13.4	37.0	25,607	29,689	16,857	72,153

Table 4-7B

CoSPA Benefit 2: Enhanced Playbook Reroute Planning and Execution (EPB)

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Facility**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**Total**
14 Jun	ZID	4.0	2.3	6.3	17,156	5,032	2,893	25,081
06 Jul	ZAU	1.3	0.7	2.0	5,576	1,635	881	8,092
21 Jul	ZBW	3.4	1.9	5.3	8,604	4,277	2,390	15,271
20 Jul	SCC	25.5	14.5	40.0	24,658	32,079	18,241	74,978
04 Aug	ZOB	24.0	13.7	37.7	23,208	30,192	17,235	70,635

Table 4-7C

CoSPA Benefit 3: Enhanced Reroute Planning – Strategic Planning Period (ERP)

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Facility**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**Total**
21 Jul	COA	4.5	2.6	7.1	4,352	5,661	3,271	13,284
04 Aug	ZOB	1.6	0.9	2.5	6,862	2,013	1,132	10,007
06 Jul	ZAU	4.4	2.5	6.9	9,038	5,535	3,145	17,718
07 Jul	ZMP	2.1	1.2	3.3	9,007	2,642	1,510	13,159
14 Jun	ZID	0	0	0	0	0	0	0

Table 4-8
Median CoSPA Delay Savings per Benefits Category

CoSPA Benefit Category	Delay Saved (hr)	Cost Savings ($)
Median AFP	57.3	113,026
Median EPB	6.3	25,081
Median ERP	3.3	13,159

4.4 ESTIMATED ANNUAL COSPA DELAY SAVINGS

The normalized frequency of observed CoSPA benefits presented in Table 4-3 (with the exception of 'AFP' applications) were summed up across all operational facilities and averaged between EAST and MIDWEST facilities to determine the total observed benefits frequency per convective weather day. Averaging the EAST and MIDWEST total frequency of occurrence of CoSPA benefits ensures that results:

(a) Coincide with the methodology of estimating annual benefits by considering the collective evaluation airspace (9 ARTCCs) as one arena for strategic planning benefits – with weather impact mitigation opportunities estimated to be present on 95 annual days (see Section 3.4);

(b) Avoid "double-counting" the potential benefits frequency (e.g., ATCSCC has normalized benefits frequency tallies for EAST and MIDWEST evaluations – these "per day" statistics need to be averaged together)

AFP benefits were handled differently. Since, within the evaluation region of this study, AFPs required for weather impact mitigation have historically only been implemented when convection is present or expected in an EAST facility, it did not make sense to average CoSPA AFP benefits frequencies between the EAST (2.1 per day) and the MIDWEST (0 per day) facilities. The total AFP benefits frequency from EAST evaluations was used as the total benefits frequency.

Multiplying the estimated CoSPA benefits frequency (and AFP benefits frequency) per convective weather day by an estimated 95 weather impact days (55 'AFP-consideration' days) yields the annual CoSPA benefits frequency (Table 4-9).

Annual CoSPA delay reduction benefits, computed from median delay savings per CoSPA use and the annual CoSPA frequency of use, are presented in Table 4-10. Combined for the three primary benefits categories, annual CoSPA benefits estimates, derived from real-time observations across all FAA and airline facilities included in the 2010 evaluation were **10,000 hours of delay saved, with a cost savings of $26.8 M.**

Table 4-9
Annual CoSPA Benefits Frequency per Category *

A

1. AFP	115
2. GDP	28
3. GS	9
4. EPB	332
5. ERP	418
6. MRR	57
7. MIL	9
8. ITR	19
9. RIF	76
10. AFM	66
11. DOP	152
12. RCM	19
13. TMA	38
14. ICR	9

B

15. SPD	646
16. SP-CCFP	513
17. I/IC	2113
18. SA-R	3771
19. SA-T	1895
20. SA	3125
21. STAFF	47
22. EQUIP	9
23. CWSU	313

* *Benefit categories in red boxes used to estimate annual delay savings*

Table 4-10
Annual CoSPA Delay Reduction Benefits

	Hours			**Monetary Value ($)**			
CoSPA Benefit Category	**Primary**	**Downstream**	**TOTAL**	**DOC**	**PVT**	**PVT downstream**	**TOTAL**
AFP	4,197	2,392	6,589	4,708,445	5,280,455	3,009,090	12,997,990
EPB	1,328	763	2,091	5,695,792	1,670,624	960,476	8,326,892
ERP	878	502	1,380	3,764,926	1,104,356	631,180	5,500,462
TOTAL	6,403	3,657	**10,060**	14,169,163	8,055,435	4,600,746	**26,825,344**

5. CONCLUSIONS

Effective air traffic management (ATM) strategic planning is critical for mitigating delays and ensuring a safe and efficient operation during NAS weather impact events. An accurate and operationally useful strategic weather forecast (2 – 8 hour forecast) is key decision support information used by FAA traffic managers and airline air traffic control (ATC) coordinators and dispatchers to proactively anticipate and plan for the onset and cessation of operationally significant weather constraints. A recent advance in strategic weather forecast technology is the CoSPA forecast. CoSPA is a high resolution (3 km) 0 – 8 hr deterministic "radar-like" forecast (updating every 15 minutes) of precipitation and echo tops. CoSPA uses CIWS short-term forecast techniques, numerical weather predictions from the High Resolution Rapid Refresh (HRRR) model for longer-term forecasts, and forecast "blending" technologies to produce seamless predictions of how convection may evolve and move with time. The CoSPA product was fully integrated with CIWS and was available on the CIWS platform at facilities with dedicated situation displays.

In 2010, a field evaluation was conducted at 17 FAA and airline dispatch facilities to assess the operational performance, strategic planning utility, and estimated delay reduction benefits of the CoSPA weather forecast. Simultaneous, real-time observations of CoSPA usage were made on 15 convective weather days (181 hours of observations) during June – September 2010.

An assessment of the CoSPA operational performance during the real-time evaluations revealed that the overall enhanced capabilities of CoSPA (compared with the baseline CCFP) to predict, with high spatial and temporal resolution, convective weather initiation, decay, organization, coverage, intensity (including vertical extent), and storm motion were valuable weather forecast attributes for aviation planners making strategic ATM decisions. Often, CoSPA forecasts were used to better define the specific regions, timing, and severity of potential convective weather constraints within the more broad and general CCFP forecast polygons, leading to enhanced situational awareness, improved strategic planning coordination, and ultimately, more effective traffic management decisions and ATM initiatives.

CoSPA forecasts were observed on occasion to over-predict, under-predict, and/or inconsistently predict convective weather coverage and severity. At times, these forecasts contributed to reduced common situational awareness and less efficient assessments of anticipated weather constraints during the strategic planning period (2 – 8 hours). As a prototype forecast technology still in development, research continues to improve the forecast capabilities of CoSPA. A targeted improvement – identified both by developers and the operational users – is to include some type of forecast uncertainty measure or metric (perhaps through the use of probabilistic forecasts) that would inform users of situations when the accuracy or consistency of the deterministic weather predictions do not, at that time, support specific strategic planning actions.

Twenty-three unique CoSPA benefits categories were identified during the operational field-use evaluation. Observed CoSPA applications included quantifiable benefits through improved strategic planning initiatives and enhanced situational awareness and improved collaborative decision-making. Specifically, CoSPA was used to assist with Airspace Flow Program (AFP) decisions about program traffic rates, timing for implementation, when to cancel an AFP, or even if an AFP was needed. CoSPA was also used to assist with Playbook reroute execution and management. Smaller, more surgical strategic reroute decisions were also planned based upon CoSPA forecasts of impacted and viable airspace. Aviation planners at Airline Operations Centers (and some FAA facilities) were observed using CoSPA to make strategic routing decisions for individual flights or city-pairs. Finally, CWSU meteorologists in FAA En Route Centers and weather specialists at the ATCSCC were also observed using CoSPA to assist with their tasks – which included CCFP collaboration and development.

CoSPA benefits case studies were analyzed in an effort to quantify the estimated delay savings associated with the three primary CoSPA strategic weather impact mitigation benefit categories [improved AFP execution and management (AFP), enhanced Playbook reroute planning and execution (EPB), and enhanced strategic reroute planning (ERP)]. Results show that per-use CoSPA benefits ranged from 3.3 hours to 145.5 hours. The variability in case-to-case delay savings followed expected trends, with the largest benefits being associated with AFP improvements and the smallest benefits being associated with enhanced reroute planning (ERP), which typically affected the fewest aircraft in the 2 – 8 hr decision period. Relatively frequent usage of CoSPA for Departures Operations Planning assistance (DOP) was also observed, but not quantified, since most of these observed uses were more qualitative in nature, making it difficult to estimate delay savings for this benefits category.

The frequency of each type of CoSPA application was tabulated for each FAA and airline facility and rolled-up to an annual CoSPA benefits frequency estimate based upon historical averages of weather impact events (accounting for longer-term climatology). Median case study delay savings per AFP, EPB, and ERP benefit category were multiplied by the estimated annual frequency of these CoSPA beneficial decisions to estimate the annual CoSPA delay reduction benefits for 2010. Estimated annual CoSPA benefits in 2010 totaled 10,000 hours of delay saved, with a cost savings of $26.8 M.

In addition to the continued research into forecast improvements, CoSPA benefits are also expected to increase as ATM strategic planning tools continue to evolve and new capabilities and procedures become available that may take better advantage of a high-resolution, rapidly-updating deterministic precipitation and echo tops forecast. Moreover, significant improvements to strategic planning and weather impact mitigation are anticipated once CoSPA weather forecasts are translated into ATM impact predictions and integrated into current and planned ATM decision support capabilities (Lin et al. 2011).

7. REFERENCES

Andrews, J., 1993: Impact of Weather Event Uncertainty Upon an Optimum Ground Holding Strategy, Air Traffic Control Quarterly, Vol. 1, pp. 59-84.

Beatty, R., R. Hsu, L. Berry, and J. Rome, 1999: Preliminary Evaluation of Flight Delay Propagation Through an Airline Schedule, Air Traffic Control Quarterly, Vol. 7, pp. 259-270.

Brennan, M, 2007: Airspace Flow Programs – A Fast Path to Deployment, Journal of Air Traffic Control, 49(1), pp. 51-55.

DeArmon, J., 1992: Analysis and Research for Traffic Flow Management, Proc. of 37th Annual Conference of Air Traffic Control Association, Atlantic City, NJ, Air Traffic Control Association, pp. 423-429.

Dupree, W., J. Pinto, M. Wolfson, S. Benjamin, S. Weygandt, M. Steiner, J. Williams, D. Morse, X. Tao, D. Ahijevych, H. Iskenderian, C. Reiche, J. Pelagatti, and M. Matthews, 2009: The Advanced Storm Prediction for Aviation Forecast Demonstration, WMO Symposium on Nowcasting, Whistler, B.C., Canada.

Evans, J., 1997: Safely Reducing Delays Due to Adverse Terminal Weather, *Modeling and Simulation in Air Traffic Management*, Lucio Bianco, Paolo Dell 'Olmo, and Amedeo R. Odoni, Eds., New York: Springer-Verlag, 185-202.

FAA, 2010: Economic Information for Investment Analysis, Prepared for Operations Research / ATO-F.

Hartman, B. 1993: The Future of Head-Up Guidance, IEEE Aerospace and Electronic Systems Magazine, 8, pp. 31-33.

Lin, Y., J. Sulkin, and R. DeLaura, 2011: Prediction of Weather Impacts on Air Traffic through Flow Constrained Areas, 2nd Aviation, Range, and Aerospace Meteorology Special

Symposium on Weather – Air Traffic Management Integration, AMS, Seattle, WA.

Phillips, C., J. Pinto, D. Albo, and M. Steiner, 2010: Diagnosis of Phase Errors in High-Resolution NWP Model Forecasts of Precipitation and Application of Improved Aviation Weather Forecasts, 14th Conference on Aviation, Range, and Aerospace Meteorology, AMS, Atlanta, GA.

Pinto, J., J. Williams, M. Steiner, D. Albo, S. Dettling, W. Dupree, D. Morse, H. Iskenderian, T. Xiaofeng, M. Wolfson, C. Reiche, S. Weygandt, S. Benjamin, and C. Alexander, 2010: Advances in the Collaborative Storm Prediction for Aviation (CoSPA), 14th Conference on Aviation, Range, and Aerospace Meteorology, AMS, Atlanta, GA.

Robinson, M. and J. Evans, 2011: An Interactive Training Approach to Support the Operational Use of Air Traffic Management Convective Weather Decision Support Tools, 2nd Aviation, Range, and Aerospace Meteorology Special Symposium on Weather – Air Traffic Management Integration, AMS, Seattle, WA.

Robinson, M., R. DeLaura, and N. Underhill, 2009: The Route Availability Planning Tool (RAPT): Evaluation of Departure management Decision Support in New York During the 2009 Convective Weather Season, 8th USA/Europe Air Traffic Management Research and Development Seminar (ATM 2009), Napa, CA.

Robinson, M., R. DeLaura, J. Evans, and S. McGettigan, 2008: Operational Usage of the Route Availability Planning Tool during the 2007 Convective Weather Season, MIT Lincoln Laboratory Project Report ATC-339.

Robinson, M., J. Evans, B. Crowe, D. Klingle-Wilson and S. Allan, 2004: CIWS Operational Benefits 2002-3: Initial Estimates of Convective Weather Delay Reduction, MIT Lincoln Laboratory Project Report ATC-313.

Welman, S., A. Williams, and D. Hechtman, 2010: Calculating Delay Propagation Multipliers for Cost-Benefit Analysis, MITRE Report.

Weygandt, S., T. Smirnova, C., Alexander, S. Benjamin, K. Brundage, B. Jamison, and S. Sahm, 2010: The High Resolution Rapid Refresh (HRRR): Recent Enhancements and Evaluation During the 2009 Convective Season, 14th Conference on Aviation, Range, and Aerospace Meteorology, AMS, Atlanta, GA.

Wolfson, M. M., Dupree, W. J., Rasmussen, R., Steiner, M., Benjamin, S., Weygandt, S., 2008: Consolidated Storm Prediction for Aviation (CoSPA), 13th Conference on Aviation, Range, and Aerospace Meteorology (ARAM), New Orleans, LA, Amer. Meteor. Soc.